Biodiesel Fuel Study:
Emission Benefits and Costs in Virginia

A Report by the
State Advisory Board on Air Pollution
Biodiesel Group
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Introduction

One tasking for the 2006 State Advisory Board on Air Pollution was to evaluate and research the costs and benefits of using biodiesel as an alternative fuel in Virginia.

The Biodiesel group developed the following mission statement for the project: Gather the necessary data to evaluate biodiesel as an alternative fuel. This should include current advantages and disadvantages as well as any potential savings with air emissions.

This study included reviewing biodiesel test data from the Department of Energy, National Renewable Laboratory (NREL) as they are considered to be the leading agency actively studying biodiesel air emissions. Additionally the study included attending biodiesel conferences held in the Commonwealth, discussions with representatives from Virginia Clean Cities' and professors from the Center of Energy and Environmental Sustainability at James Madison University, and reviewing published documentation on this subject matter.

Executive Summary

Biodiesel has become a popular alternative fuel here in the United States the last 30 years. It is a non-toxic, renewable energy source produced from agricultural crop. The most common source in the United States is soybeans. After producing raw biodiesel it is normally blended into diesel fuel. For an example, one gallon of a B20 blend contains 20 percent biodiesel and 80 percent diesel fuel.

Over the last 20 years, there have been over 80 scientific studies all aimed at measuring the emissions from biodiesel. As shown in ES-Table 1, there can be significant emission gains in both regulated and non-regulated pollutants when biodiesel is used in diesel engines. Biodiesel can be used in any diesel engine with little to no modification to that engine.

ES-Table 1 EPA Estimated Emissions from B20 Blend.[1]

Emission Type	Percent Change in Emission for B20
Regulated:	
◘ Total Unburned Hydrocarbons	-20%
◘ Carbon Monoxide	-12%
◘ Particulate Matter	-12%
◘ NOx	+2%
Non-Regulated:	
◘ Sulfates	-20%
◘ PAH (Polycyclic Aromatic Hydrocarbons)	-13%
◘ nPAH (Nitrated PAHs)	-50%
◘ Ozone potential of speciated HC	-10%

Currently, the United States is producing approximately 150 million gallons of biodiesel. As new production facilities continue to break ground and current facilities expand their production capabilities, the United States could be producing up to 1.4 billion gallons of biodiesel in the next couple of years.

Biodiesel has always been associated with diesel engines. However it can also be used in home and industrial furnaces. The price of heating oil has doubled since 2001 and this has allowed the price gap between heating oil and biodiesel to close. When oil shortages occurred after the devastation from Hurricanes Katrina and Rita struck, home and business owners alike began to look for alternative heating fuels. In the Mid-Western states that choice was biodiesel since it was readily available. Now, home and business owners in upper New York and New England

have been inquiring about biodiesel supplies from their oil companies. This new awareness has convinced heating oil executives to start marketing biodiesel as a substitute for home and industrial heating oil in these regions.

The US economy is highly dependant on transportation to move goods throughout the country. Ninety-seven percent of the US transportation industry is dependent on diesel fuel and imported oil accounts for the largest component of the US trade deficit. In fact, at $60 per barrel, the US exports $700 million dollars per day to import this product. With on-going concerns about the Middle East policies/stability and crude oil prices established by Organization of the Petroleum Exporting Countries an alternative fuel is clearly forthcoming. Ideally, an alternative fuel should be cost effective, universally applicable and provide significant environmental benefits. Biodiesel meets most of those objectives and is clearly the current frontrunner in the alternative fuel market. Biodiesel should not be viewed as the panacea to liberate the US from depending on foreign oil, but rather it should be viewed as a step in the right direction that also benefits our air quality and farm communities.

Background

The use of biodiesel as a fuel source dates back to the mid-to late 1800's. Steam engines were widely used with industrial activities such as, forging iron, grinding grain and weaving textiles. However, these steam engines were largely inefficient. These engines were also expensive and only the largest industrial companies were able to afford them.

Small manufacturing companies were at a distinct disadvantage with minimal capital resources to purchase expensive steam engines. Additionally, the majority of small companies in need of this type of engine were located in rural areas. In general, their facilities were smaller in scale than those located in an industrial city.

An inventor by the name of Rudolph Diesel recognized these shortcomings and envisioned building an affordable engine to allow small manufacturing companies to compete against the larger firms. The design of his new engine would be powered from the oil of local crops that were abundantly growing in their rural lands. In 1892, he received a patent for a "Working Method and Design for Combustion Engines."[2] By 1893, his first model engine was running with 26% efficiency.[3] This was a remarkable feat since it more than doubled the efficiency of the steam engines of that era.[4] Finally, in February 1897, he ran the first engine deemed suitable for practical use, which operated at an unbelievable efficiency of 75 percent.[5] He then presented his compression ignition engine at the Exhibition Fair in Paris, France, in 1898 using peanut oil as its fuel.[6] Since then, the compression ignition engine has been called a "Diesel" engine.

In the early 1900's gasoline powered automobiles were introduced. Oil companies began refining large amounts of crude oil to keep up with gasoline demand which resulted in a surplus of petroleum distillate. Meanwhile, durability experiments on Diesel's engine indicated that peanut oil was causing premature engine failure.[7] Refining petroleum distillate became cheaper and as it became plentiful, diesel engines were adapted to run on petroleum distillate.

Rudolf Diesel truly believed that utilization of a biomass fuel was the real future of his engine. Mr. Diesel and other scientists were also concerned about the eventual depletion of petroleum and they continued to experiment with peanut oil. In 1912 he stated, "The use of vegetable oils for engine fuels may seem insignificant today. But such oils may become in course of time as important as petroleum and the coal tar products of the present time."[8] Eventually, scientists

discovered that when vegetable oil was transesterified with alcohols the diesel engine did not exhibit any failures. These early experiments led to what is known today as biodiesel.

In the latter part of the 20th century the price of petroleum distillate rose, and subsequently there was a renewed interest in biodiesel as an alternative fuel source.

What is Biodiesel?

Biodiesel is the name for a variety of ester-based oxygenated fuels derived from a biomass such as living organisms or their metabolic byproducts. It is non-toxic and a biodegradable fuel that can serve as a substitute or an additive for petroleum diesel. The most common method to produce biodiesel is to first create a base stock by pressing the seeds of various vegetable crops, the most common crop in the US being soybean, and extracting the oils. The oil is then subjected to a chemical reaction called transesterification that converts vegetable oil triglycerides into methylated fatty acids. The four key ingredients to produce biodiesel are:

1. Vegetable oil
2. Methanol or ethanol
3. A catalyst such as Sodium Hydroxide (NaOH) or Potassium Hydroxide (KOH)
4. Heat

Figure 1 is a flow diagram of the transesterification process. The vegetable oil is added into a reactor then mixed with an alcohol, such as methanol or ethanol, and a catalyst, such as potassium hydroxide (KOH) or sodium hydroxide (NaOH). The mixture is then heated and the transesterification takes place. Essentially biodiesel is a long chain fatty acid with an alcohol attached.

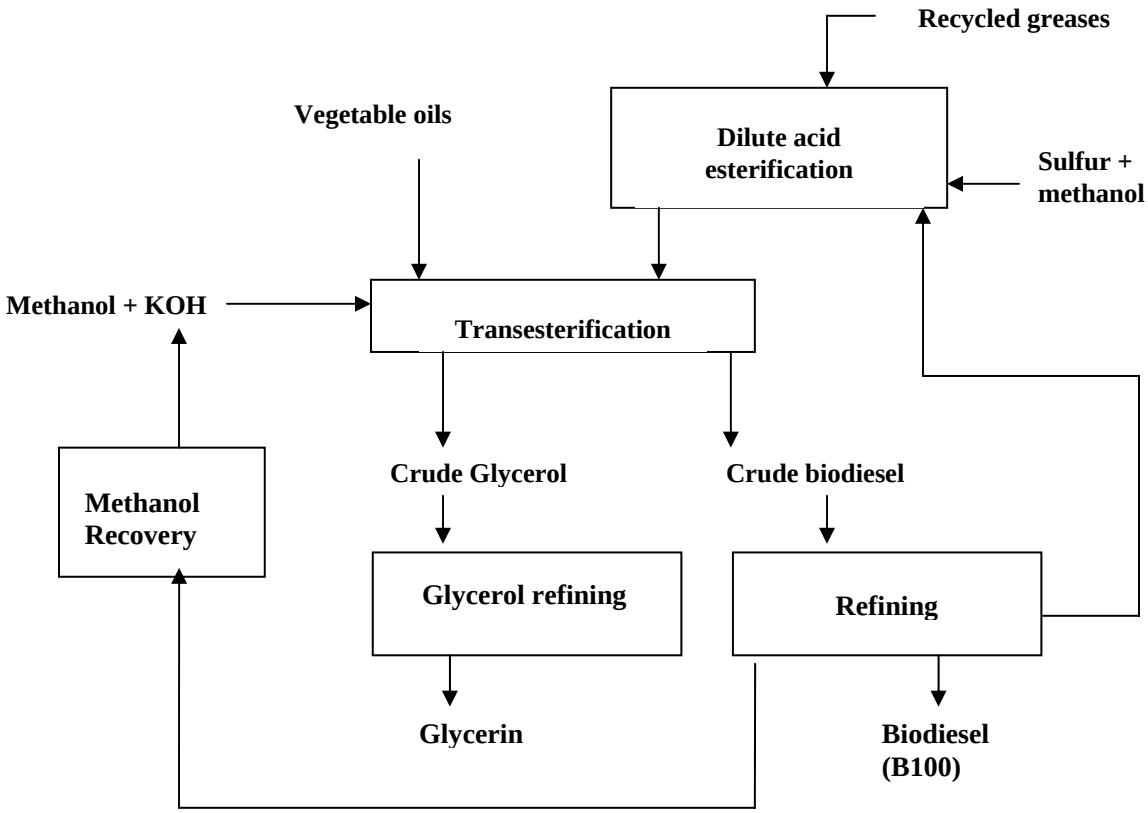


Figure 1. Transesterification flow diagram[9]

The end products from this process are neat biodiesel (known as B100) and glycerol. These byproducts are separated and purified, and the excess alcohol is recovered and reused. The glycerol can be sold to food and beverage, pharmaceutical, cosmetic and paper industries. Currently, there is a surplus of glycerol, and research is underway to develop new uses.

As shown in Figure 1, recycled cooking oils and animal fats such as beef tallow or fish oil can be used as the feedstock. Although there is a slight difference in the process, the end products remain the same.

As noted above, soybean is the chosen crop in the US because it is widely available and it is produced in excess of its need as a food product.[10] In 2004, the soybeans were planted on 75.2 million acres, which represents nearly 17 percent of the total available US cropland.[11] The 2004 harvest produced 3.1 billion bushels (85.49 metric tons) of soybean and approximately one-third of that harvest was exported throughout the world.[12] According to the Unites States Department of Agriculture (USDA), the Commonwealth of Virginia accounted for 21 million bushels of soybean harvest during 2004.[13]

Biodiesel Nomenclature

Biodiesel is used as a pure fuel source as well as in a variety of blends with diesel fuel. To identify the type of biodiesel blend the letter 'B' is used followed by a numerical value. The numerical value represents the percentage of biodiesel blended into the diesel fuel. The most common blends are listed in Table 1.

Table 1. Common Blends of Biodiesel

Blend	Mixture
B2	A mixture of 2% biodiesel and 98% petroleum diesel fuel
B5	A mixture of 5% biodiesel and 95% petroleum diesel fuel
B10	A mixture of 10% biodiesel and 90% petroleum diesel fuel
B20	A mixture of 20% biodiesel and 80% petroleum diesel fuel

Biodiesel can be blended into any of the commonly used diesel fuels on the market such as high-sulfur, low-sulfur or ultra-low sulfur fuel. In some cases, in colder climates, it is also blended with No.1 diesel better known as kerosene. Blending of the fuel can be conducted locally where the fuel is stored but it is usually blended by the fuel distributors.

Physical Properties of Biodiesel

Some of the physical properties of pure biodiesel (B100) are different than the properties of diesel fuel. Table 2 lists the primary differences: the heat of combustion, cetane number and viscosity. These properties are "typical" and will vary slightly due to the type of vegetable crop used as a feedstock and the refining process of petroleum diesel.

Table 2. Physical Properties of No. 2 Diesel and Biodiesel[14]

Fuel	Fuel Weight (lbs/gal)	Heat of Combustion (BTU/gal)	Cetane Number	Viscosity (centistokes)
No. 2 diesel	7.05	129,500	45-48	3.0
B20	7.1	127,259	50	3.3
B100 Biodiesel	7.3	118,296	55	5.7
Straight Vegetable Oil	7.5	130,000	35-55	40-50

The heat of combustion can be defined as the energy content of the fuel measured in British Thermal Units (BTU's). A BTU, by definition, is the amount of energy required to raise

temperature of water by one degree Fahrenheit. Fuels with higher energy content will usually produce more power per pound of fuel. The energy content of conventional diesel fuel can vary up to 15 percent from supplier to supplier or from summer to winter.[15] As shown in Table 2 a blend of B20 versus No. 2 diesel has a 1.73 percent lower BTU content. Dynamometer tests conducted by the Department of Energy, National Renewable Laboratory (NREL) have confirmed this drop in energy content.

The viscosity of fuel is important because it directly affects the atomization of fuel when it is injected into the engine's combustion chamber. In order to produce a more complete burn in the cylinder, fuel should enter as small droplets. As shown in Table 2, straight vegetable oil has a much higher viscosity then No. 2 diesel. Therefore, if used as a fuel, the higher viscosity will allow large droplets to enter the combustion chamber, and it will not burn as efficiently. The large droplets will remain as unburned fuel, and they will build up or "coke" injector tips, intake and exhaust valves, which can lead to premature engine failure. B20 has a slightly higher viscosity than No. 2 diesel and there is a slight concern from engine manufacturers that injectors and valves may possibly develop deposits over time.

Cetane rating is also a very important property of diesel fuel as it is a measure a fuel's self-ignition or fuel volatility. Fuels that are more volatile have higher cetane ratings. Cetane is an important fuel property because it can affect the performance of a diesel engine during cold starting, warm up and ultimately the emissions. Since cetane reduces ignition delay, the combustion process starts earlier and emissions (primarily carbon monoxide and hydrocarbons) are reduced.[16] Fuels with high cetane ratings such as straight vegetable oil, will cause rapid ignition and thus not allow enough time for the fuel to mix with air to complete the combustion cycle.

Regulatory Drivers

In President Bush's State of the Union Address in 2006 he stated, "America is addicted to oil which is often imported from unstable parts of the world."[17] Imported oil accounts for the single largest component of the US trade deficit. In fact, at $60 per barrel, the US exports $700 million per day to import this product. Additionally, federal policymakers have also established several initiatives that require the use of alternative transportation fuels such as biodiesel. Senator Peter G. Fitzgerald (R-IL) said, "We are at the mercy of OPEC and other overseas oil producers. When they want to strangle the U.S. economy, all they have to do is turn off the spigot. Among other

things, we need to look at increasing domestic energy production and reducing our reliance on foreign oil."[18]

There are several alternative fuels that have been developed and are currently on the national market. Unfortunately, many require significant engine modifications or fuel storage upgrades. Ideally, an alternative fuel should be cost effective, universally applicable and provide significant environmental benefits. Studies have shown that recycled restaurant grease will meet these requirements; however, the sources for recycled grease are limited in quantity. Biodiesel meets some of these requirements and is clearly the front runner of all currently market alternative fuels.

The President's Advance Energy Initiative calls for replacing 75 percent of oil imports from the Middle East by 2025. Tom Verry of the NBB said, "Of the amount of crude oil America imports from Iraq, 1.85 billion gallons are refined to diesel fuel. If 5 percent biodiesel were added to all of the 37 billion gallons of on-road diesel in the US, it would displace 1.85 billion gallons. At 10 percent, we would displace all of the oil that comes from Saudi Arabia."[19]

Nationally, the trend for using biodiesel started with the Energy Policy Act of 1992. This act required federal and state entities that control 50 vehicles weighing 8,500lbs or more to acquire alternative fuel vehicles.[20] Some fleets like the New Jersey Highway Department and the U.S. Postal Service began to use biodiesel in their diesel trucks with little to no modification to their engines. The EPA further amended the act in 1998 to include the use of biodiesel as an alternative fuel. The provision allowed fleets who purchase 450 gallons of biodiesel, consumed in at least a blend of 20 percent biodiesel and 80 percent diesel, to earn one alternative vehicle purchase credit.

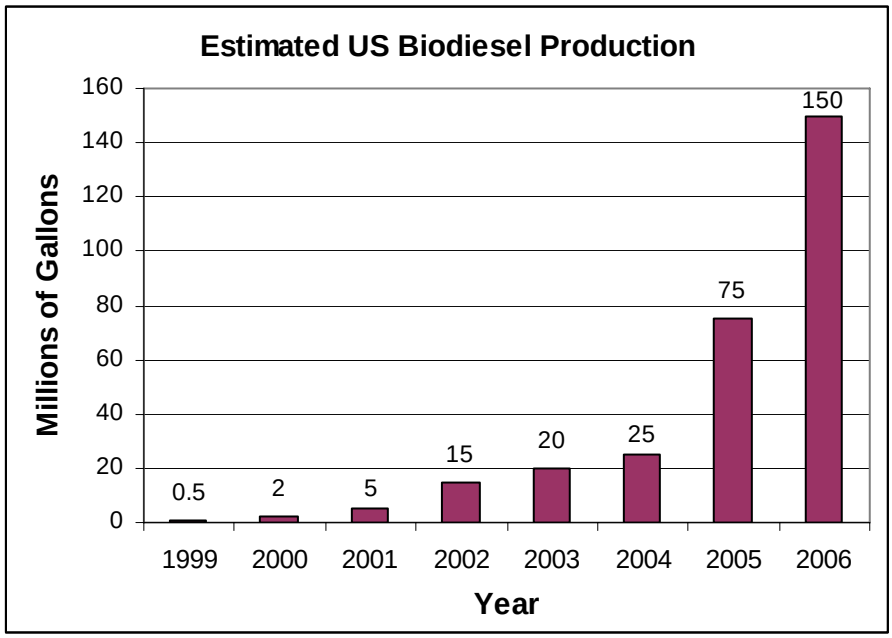
Three more executive orders were released from 1998 through 2000. These orders promoted the use of biofuels and set specific goals to reduce petroleum consumption by at least twenty percent in 2005. The results of this legislative boost were immediately obvious, and the use of biodiesel grew exponentially in the following years.

Biodiesel Production and Infrastructure

As the biodiesel demand grew, infrastructure and plant development rose. In 1999, the US produced approximately 500,000 gallons of biodiesel. It is estimated in 2006 the US will produce

150 million gallons of biodiesel. Table 3 shows the increase in production from 1999 through 2006.

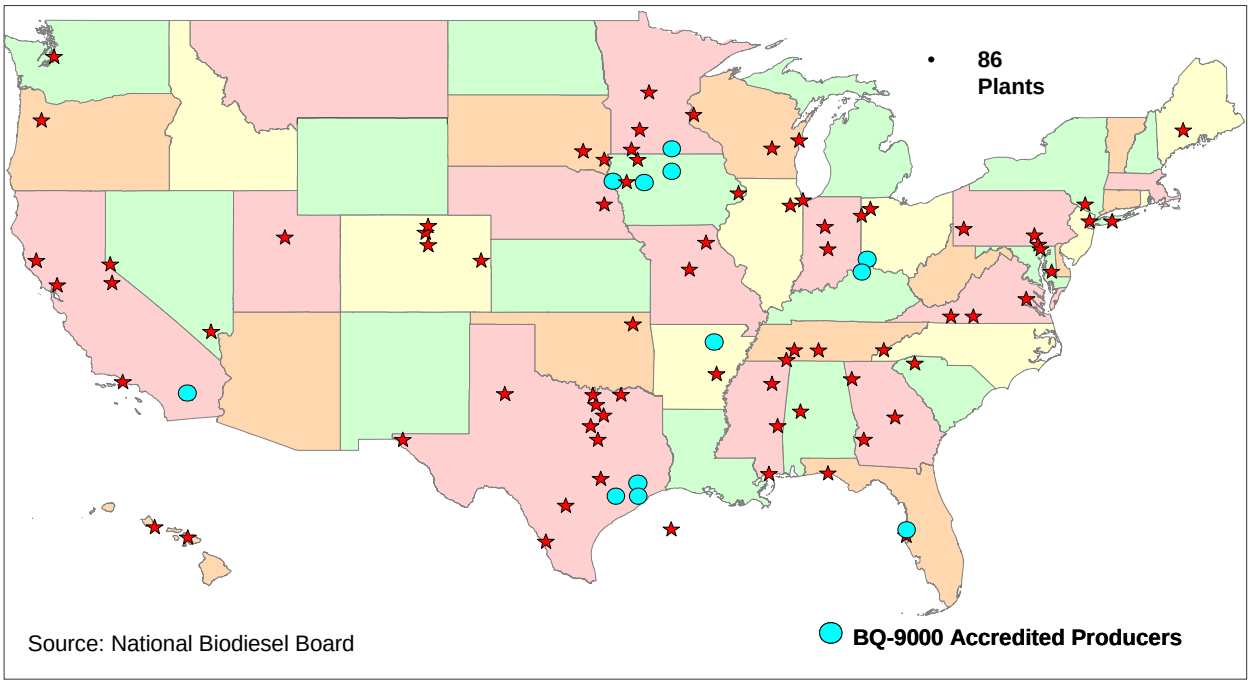
Table 3. U.S. Production of Biodiesel[21]



There are presently sixty-five companies that have invested millions of dollars into the development of biodiesel manufacturing plants and are actively marketing biodiesel. These sixty-five facilities have the capacity to produce annually a combined total of 395 million gallons per year.[21]

Below is a graph showing the trend of biodiesel plant production at the national level as indicated by the National Biodiesel Board (NBB).

Graph 1. Current U.S. Biodiesel Production Facilities[22]



As of September 2006, there are an additional sixty-five plants under construction throughout the United States. Additionally, thirteen of the facilities shown in Graph 1 are currently expanding their plants to increase their production capabilities. In Richmond, Virginia one plant is currently under construction and they are expecting to have the production capacity of 10 million gallons of biodiesel per year. Upon completion of these construction projects, the NBB anticipates a U.S. annual production capacity of nearly 1.4 billion gallons per year.[23]

Virginia's Biodiesel Initiatives

Biodiesel production has received a lot of attention in the last couple of years at both the state and federal levels. It is likely to gain even more momentum with the ever increasing cost of crude oil. In Virginia, the House Joint Resolution 598 from the 2005 General Assembly requested that the Secretary of Agriculture and Forestry study the use and production of biodiesel fuel in Virginia. They were tasked to pay particular attention to the capability and desirability of generating a minimum demand of 20 million gallons annually in the Commonwealth.

A Biodiesel Workgroup was formed and they developed twelve findings. Listed below are the items that are pertinent to the State Air Board:

1. The Workgroup lacked the financial resources and expertise to conduct an analysis of the economic impact of the use of biodiesel on the state, the agricultural community,

petroleum marketing and distribution, and biodiesel consumers, as well as the supply of biodiesel fuel and demand for biodiesel fuel in the Commonwealth. No funding was appropriated to the Secretariat that would have allowed the Workgroup to hire a qualified consultant to assist in the completion of this analysis.

2. Biodiesel studies that have been conducted in the Commonwealth and in other states focused on the feasibility of locating a biodiesel production plant in a specific location within the state. It would be virtually impossible to conduct a feasibility study for the development of a biodiesel production plant that would apply throughout the Commonwealth.

3. Industry sources maintain that the current level of degummed soybean oil production within the Commonwealth combined with import sources is adequate to produce 20 million gallons of biodiesel stock annually. The current production capacity for refined soybean oil is approximately five million gallons annually. The majority of the product is sold outside the Commonwealth.

4. There is a need for increased education and awareness of biodiesel.

5. There are several Federal tax incentives available to biodiesel producers and users. These incentives are contained in the American Jobs Creation Act of 2004, Clean Air Act Amendments of 1990, Energy Policy Act of 2005, International Fuels Tax Agreement, and Farm Security and Rural Investment Act of 2002.

6. Only a small number of states have created state level incentives for biodiesel and other renewable fuel sources. At the current time, Maryland is the only state contiguous to Virginia offering a state level tax incentive. In 2005 the Maryland legislature adopted a Renewable Fuels Promotion Act Tax Incentive. As the number of states offering incentives increases, the possibility of Virginia losing fuel sales due to lower prices in neighboring states will also increase.

7. Several local governments, universities and the Department of Transportation in Virginia are currently using biodiesel. The Clean Cities Program works with these groups to advance the nation's economic, environmental, and energy security by

supporting local decisions to adopt practices that contribute to the reduction of petroleum consumption.

8. The Virginia Soybean Association, through funding from the Virginia Soybean Board, has sponsored a Biodiesel rebate program for four years.

The Workgroup recommended the General Assembly not mandate the use of biodiesel fuel. They encouraged funding of Virginia Department of Agriculture and Consumer Services to promote and market biodiesel, evaluate the tax structure in order to make biodiesel a competitive fuel source, and have the Commonwealth support the use of biodiesel and its use in their fleet vehicles.

Biodiesel is not specifically defined within the Virginia Code however it does fall under the definition of biofuels. The 2006 General Assembly passed HB680 sponsored by Delegates Rob Wittman and Bill Barlow and Senator Frank Ruff.[24] This bill established an incentive grant program for producers of biofuels. To be eligible for the grant money, a producer must produce in excess of 10 million gallons of neat biofuels within the Commonwealth in a calendar year using feedstock originated from within the US. Producers that qualify will receive a $0.10 per gallon incentive. Currently there is $1 million ear-marked for this grant program.

According to Virginia Office of National Agricultural Statistics, soybeans rank as the top row crop in the Commonwealth with over 530,000 acres planted in 2004 (the last year for hard data). Soybean was also the top cash crop coming in at just over $124 million.[25] On average, soybeans will produce 49 gallons of biodiesel per acre, therefore Virginia has the potential to produce nearly 26 million gallons of biodiesel per year. However, the availability of land is more than 530,000 acres as Virginia has a vast array of land usage. To pinpoint a specific acre usage for soybeans at the exclusion of other viable agriculture ventures would be nearly impossible.

The Cost and Production of Biodiesel

The greatest expense in producing biodiesel is the cost of the feedstock. For example, it takes about 7.5 pounds of soybean oil at a cost $0.21 per pound to produce a gallon of biodiesel. This accounts for 70 percent of the direct costs.[26] Therefore, feedstock costs alone are at least $1.58 per gallon. With marketing, overhead and profit, the finished biodiesel cost is typically slightly over $3 per gallon.

In order to offset these costs and promote the use of biodiesel, the United States Department of Agriculture offers grants to produce biodiesel through the Commodity Credit Corporation (CCC). The producers of soybean biodiesel receive $0.89-$0.91 per gallon and the exact rebate on the amount per gallon is based on their production levels.

Additionally the federal transportation bill passed in 2004 includes excise tax credits for biodiesel blending. This legislation allows blenders to claim a credit against the applicable Federal motor fuels excise tax if a batch of diesel fuel contains biodiesel. If the blend is from virgin oil, such as soybean, they can receive a credit of $1 per gallon of biodiesel. If the blend is from recycled oil, such as restaurant grease, they can receive a credit of $0.50 per gallon of biodiesel.

Biodiesel producers are trying to reduce these feedstock costs by a variety of methods including the development of hybrid soy plants and using other vegetable oils with higher oil content. Another possibility is to supplement the biodiesel with yellow-grease. Yellow-grease is essentially used frying oil that is often available at low (approximately $.05 per pound) to no cost at all. It is estimated that by employing either one of these strategies, the future cost of feedstock can be significantly reduced making biodiesel less expensive to produce than petroleum-based diesel. The Department of Energy has forecasted that biodiesel produced from yellow-grease will cost approximately $1.40 per gallon by 2010.[27]

Brown grease is yet another potential source. Brown grease is better known as the grease entrained in water that enters the sanitary sewer system by household and industrial drains. Some sanitation districts are experiencing difficulties with the amount of brown grease traveling through their pipes that end up causing blockages and eventually sewage spills. Grease blockages in Sacramento, California accounted for 44% of annual mainline blockages between 1996 and 2000. These grease blockages caused several sewage spills costing an average of $235,000 in repairs during that four-year period.[28] California has since reacted to the problem and is now requiring all new restaurants to install interceptors to remove grease from sewage water. A study by NREL estimates that the average American accounts for 9 pounds of yellow grease per year and 16 pounds of brown grease per year.[29] On average, every American citizen generates 25 pounds of waste grease per year.

The Energy Gained from Biodiesel

Proceedings of the National Academy of Sciences published a University of Minnesota comprehensive analysis of the full life cycle of soybean biodiesel. The researchers tracked all the energy used for growing soybeans and converting the crops into biofuels. They concluded that soybeans return 93 percent more energy than is used to produce it.[30]

Home and Industrial Heating Oils

Biodiesel has always been associated with diesel engines. However it can also be used in home and industrial furnaces. The price of heating oil has doubled since 2001 and this has allowed the price gap between heating oil and biodiesel to close. When oil shortages occurred after the devastation from Hurricanes Katrina and Rita struck, home and business owners alike began to look for alternative heating fuels. In the Mid-Western states that choice was biodiesel since it was readily available. Now, home and business owners in upper New York and New England have been inquiring about biodiesel supplies from their oil companies. This new awareness has convinced heating oil executives to start marketing biodiesel as a substitute for home and industrial heating oil in these regions.

Biodiesel can either be used in a blend with heating oil or pure B100 with no modifications to the burning equipment. On average, most homes burn 800 gallons of heating oil per year. At today's biodiesel prices, that equates to extra $50 per year for a B5 blend and $750 per year for a B100 blend per household. However, the attraction to using biodiesel in a home or industrial furnace is the reduction in service cleanings. It is widely known that poor fuel quality and the sulfur in the fuel can contribute to the fouling of oil heat burners. A fouled burner lowers the efficiency of the heating system and that requires more frequent cleaning. When biodiesel is used as a blend, the sulfur is dramatically reduced. When biodiesel is used as B100, there is no sulfur in the fuel. Since biodiesel is a natural solvent the oil heat burners stay clean. The school district of Warwick, Rhode Island has been using a B20 blend in their school furnaces since 2001 and they have not experienced any maintenance issues related to their use of biodiesel.

Emission Testing with Biodiesel

Biodiesel also became the only alternative fuel to pass the EPAs Tier I and Tier II Health Effects Testing under the Clean Air Act Section 211(b) in 2000. These programs are by far the most

stringent emissions testing protocols ever required by the EPA for certification of fuels or fuel additives.[31]

Over the last 20 years, there have been over 80 scientific studies all aimed at measuring the emissions from biodiesel. However, most of emissions tests were conducted on pre-1998 diesels. The majority of these studies were conducted in engine dynamometers as opposed to actual in-field studies.

In 2002, the EPA released a draft technical report on biodiesel emissions. This report included various statistical analytical tools to compile the results from thirty-nine studies that met their criteria. The EPA attempted to develop initial models predicting how various duty-cycles, engine age/type, and fuel properties would affect biodiesel emissions. In addition; they summarized the results to identify the average expected emissions reductions with the use of B20. Table 4 provides the expected criteria pollutants emission reductions for virgin soybean-based biodiesel added to an average low-sulfur (<500 ppm) diesel fuel.

Table 4. EPA Estimated Emissions from B20 Blend.[32]

Emission Type	Percent Change in Emission for B20
Regulated:	
◘ Total Unburned Hydrocarbons	-20%
◘ Carbon Monoxide	-12%
◘ Particulate Matter	-12%
◘ NOx	+2%
Non-Regulated:	
◘ Sulfates	-20%
◘ PAH (Polycyclic Aromatic Hydrocarbons)	-13%
◘ nPAH (Nitrated PAHs)	-50%
◘ Ozone potential of speciated HC	-10%

The data set used in the EPA's report was based on a dynamometer testing procedure that is normally used for new engine emission certification. The EPA has found that dynamometers are excellent for testing and certifying new engines, however dynamometers are not a true reflection of predicting "real world" engine emissions. The EPA is moving towards the use of portable emission measurement systems (PEMS) to test real-world duty cycle engines that are currently in the fleets. Also, to employ a dynamometer for testing is expensive and can cost up to $300,000.

Many facilities that are using biodiesel have forgone the emission testing because of this large expense. The emissions data set using PEMS is fairly small and is not considered statistically significant, however, the results are promising for NOx emissions. The North Carolina Department of Transportation employed a PEMS in 2005 testing B20 versus No. 2 diesel in twelve of their dump trucks. The testing was conducted with the truck loaded and unloaded while they traveled on their normal route, thus accounting for a normal duty cycle. The results showed an average decrease in NOx by 14 percent when they used a B20 blend versus No. 2 diesel.[33]

The Brookhaven National Laboratory on Long Island, New York completed emissions testing with biodiesel home heating blends in 2001. No noticeable changes in performance were observed and revealed reductions in carbon monoxide and nitrogen oxide emissions. Additionally, they measured a 97.5% decrease in carbon dioxide emissions when compared to regular home heating oil.

Why the NOx Increase with Diesel Engines?

The University of California at Berkeley and the Lawrence Livermore National Laboratory have been reviewing previously published theories for the slight NOx increase from burning biodiesel. Their studies propose that the reason for the slightly higher NOx is due to the molecular structure of the soybean oil.[34] They indicate that soybean oil has more double-bonds when compared to No. 2 diesel and results in a higher flame temperature that causes a slightly higher NOx exhaust.

The current view of NOx from the NREL is that NOx emissions are engine dependent. In some engines, NOx will go up and in others it will go down, but on average NREL believes NOx with fluctuate between +/-2 percent depending on the engine. The NREL will publish results of their study later this year.[35]

The Emission Changes with New Diesel Engines

Since the mid 1990's, the EPA has pursued a program to dramatically tighten the regulated emissions on new diesel engines. For example, referring to Table 5, the 2007 heavy-duty engine using No.2 low sulfur diesel will decrease PM emissions by 98 percent from a 1990 baseline and 90 percent from a 2000 baseline. The EPA has required engine manufacturers to reduce NOx and non-methane hydrocarbon (NMHC) in engines built in 2004 and beyond. However, studies have

shown that because the emission targets do not affect existing diesel engines, the full effect of the emission reductions will take more than 20 years to achieve.

Table 5. Emission Requirements for New Diesel Engines[36]

Regulated Emission	2000 Standard (g/bhp-hr)	2004 Standard (g/bhp-hr)	2007 Standard (g/bhp-hr)
NOx	4.0	-	0.20
HC	1.3	-	0.14
NMHC +NOx	-	2.4	-
CO	15.5	15.5	15.5
PM	0.10	0.10	0.01

In order to meet these EPA mandates, engine manufacturers are installing exhaust after treatment devices on their engines. For 2007 engines two emission control devices are being installed on the diesel engine exhaust. The first is a diesel particulate filter (DPF) and the second is an oxidation catalyst. The DPF is installed in place of the muffler, and it is designed to trap the particulate material in diesel exhaust. However they do soot and periodically they have to be cleaned or replaced. Because of their cost, engine manufacturers have installed a passive regeneration process to keep the DPF clean by installing a precious metal catalyst in the DPF. In the presence of heat (exhaust gases), the trapped particulate matter (i.e. soot or carbon) is converted to carbon dioxide. This reaction requires a certain exhaust temperature. If the temperature is too low, a small amount of diesel fuel is injected into the exhaust stream, thus increasing the exhaust temperature allowing the reaction to start.

Sulfur dioxide is a by-product of burning diesel fuel and in large concentrations it will act as a poison which will attack and destroy the precious metal catalyst. Therefore, the EPA has mandated U.S. refineries to start producing ultra-low sulfur diesel (ULSD) containing a maximum of 15 ppm of sulfur. This fuel will replace the current on-road low-sulfur diesel that contains 500 ppm of sulfur, by October 2007 and will allow the engine manufacturer's to install the DPF with a passive regeneration catalyst.

Removing the sulfur from diesel fuel can create problems for the older diesel engines that will still be operating in the US. Those engines use the sulfur in the fuel to lubricate the injection pump and injectors. Without the sulfur, the pumps could suffer seal damage.

The Lubricity Advantage of Using Biodiesel

Diesel fuel lubricity is measured by a standard developed by the American Society of Testing and Measurements (ASTM). The test measures the amount of wear or scarring that occurs between two metal parts when they are lubricated with diesel fuel. As mentioned above, fuel lubricity is important for rotary and distribution type fuel injection pumps in older diesel engines. Biodiesel is a natural lubricant, and it does not contain any sulfur or aromatic compounds. Testing by the Stanadyne Automotive Group shows that by using a B2 blend in any conventional diesel fuel is sufficient to address any lubricity concerns.[37]

The NBB lists several other environmental and economic advantages with using biodiesel. Their list is compiled in Appendix A.

Biodiesel Disadvantages

One of the biggest challenges with biodiesel is distribution. The majority of the biodiesel production facilities are located in the Midwestern States and biodiesel is usually shipped by rail tanks or by truck to local distribution centers. Biodiesel has a propensity to mix with water and therefore cannot be shipped through the major pipelines that carry diesel fuels. Listed below are the disadvantages with biodiesel:

1. Cold Flow Impacts:

ASTM has developed two tests that check the cold flow properties of diesel fuel. They are the cloud point and cold filter plugging point. The cloud point is the temperature at which small solid crystals are first visually observed when diesel fuel is cooled. Cold filter plugging point is the temperature at which fuel will cause a filter to plug due to the fuel composition. This usually results in the fuel gelling or crystallizing.

In most diesel engines today, fuel is used to lubricate and cool the injectors. The excess fuel is brought back to the diesel fuel tank. The warm fuel is use to keep the fuel in the tank from gelling in cold climates. This is, in part, why truck drivers keep their engines running overnight at truck stops.

Over the last seven years, biodiesel has been thoroughly tested for both of these conditions. Biodiesel blends (primarily B20) have been used in a variety of climates

without cold flow problems. However, soybean based B100 can reach the cloud point at 32º F. Table 6 lists the cloud point temperatures for each of the common soybean blends:

Table 6. Cloud Points of Biodiesel Blends[38]

Blend	Cloud Point Degrees F
B10	5
B20	7
B30	14
B50	18
B100	32

To aid B100 in cold climates where freezing temperatures are common, above ground storage tanks should be insulated, agitated, heated to keep the product from gelling. This precaution includes tanks, pumping equipment, and the vehicles themselves.

Additionally, cold flow additives that are currently used for No. 2 diesel can be added to a blended biodiesel. Depending on the additive, it can lower the B20 cloud point to -12 º F with no other effects.[39]

2. The Lack of Standards:

When large scale production of biodiesel began in 1996, there were very little standards set in place for producing neat biodiesel. To alleviate this issue, the ASTM developed specifications for B100 called ASTM D6751-03 that created a standard product that is suitable to be blended in diesel fuel.

Additionally, in 2005, the NBB developed BQ-9000. This is a voluntary program that combines the ASTM standard with a rigorous quality assurance program. BQ-9000 is designed to ensure biodiesel producers and distributors follow a fuel testing program to reduce any chance of producing or distributing inadequate fuel. To receive accreditation, companies must pass a thorough review and inspection of their quality control processes by an independent auditor.

There is concern of the rapid growth in equipment sales to “homebrew” biodiesel. Several companies on the internet are soliciting equipment for individuals to produce

their own biodiesel to use in their diesel engines or home heating. Normally, this equipment is not intended mass production or resale there are concerns about the quality of the fuel that is produced and the safe handling of the chemicals involved in the process. Often times, the instruction for these "homebrew" reactors come with very little instruction. In Virginia, James Madison University (JMU), Center for Energy and Environmental Sustainability, was tasked by the Virginia Department of Mines, Minerals and Energy (VDMME) to research these products and report on the small-scale reactor performance and safety related issues. JMU has completed this report and has submitted their findings to VDMME.

3. The Increase in NOx Emissions:

Several research facilities are investigating the NOx emission increase when using biodiesel. Some point to the higher levels of polyunsaturates and the amount of double hydrogen bonds found in biodiesel. While Biodiesel fuel exhibits emission reductions of carbon monoxide (CO), particulate matter (PM), and volatile organic compounds VOC, an increase of NOx emissions has been documented in tests and the percentage of the increase rises as the concentration of biodiesel is increased. B20 has shown an increase of NOx of 2 percent and B100 has shown an increase of 9 percent.[39] There have been numerous studies on the effects of biodiesel fuel on diesel engine emissions, but the effects of biodiesel on air quality have not been quantified. NREL developed a model that replicated the heavy duty diesel engine population of Southern California and calculated the emissions if 50 and 100 percent of these engines used B20 in place of No. 2 diesel. The model test concluded that if B20 was used, the changes in air pollutant concentrations would not affect or exceed the 1-hour or 8-hour ozone concentration limits.[40] Therefore, in regions where NOx is problematic for attaining 1-hour and 8-hour ozone standards, a B20 blend will not adversely impact those regions.

4. Fuel System Components of Older Engines:

Urethane rubber components and neoprene seals of fuel systems in diesel vehicles can be incompatible with biodiesel as the same qualities that cause it to absorb water can cause deterioration of such components. Most pre-1994 vehicles and a few later model cars may have rubber fuel lines and/or rubber seals in the fuel system. Biodiesel will gradually swell the rubber and degrade it. Also, biodiesel is a solvent that will dissolve any sludge

deposited by diesel fuel. If the amount of residue is high, this could also clog the fuel filter.[41]

5. Energy Content:

B20 has an energy content that is about 10% less than No. 2 diesel. The sample size for in-field tests are small, however, dynamometer testing has confirmed that on average it will take 1.1 gallons of B20 to do the same work as one gallon No. 2 diesel. Blends with B5 show no significant change in properties when compared to No. 2 diesel.

6. Uses for Glycerin:

As previously mentioned glycerol is used as a base stock for the food and beverage, pharmaceutical, cosmetic and paper industries. Currently, there is a surplus of glycerol, and further research is required to develop new uses.

Biodiesel versus other additives on the market

Various additives are available that can be blended with ordinary diesel fuel to reduce emissions. As part of this analysis, literature from two such products is included in Appendix B. This is information is provided as an example of additives and is not be construed as an endorsement of either product.

Conclusions

Biodiesel is a renewable, biodegradable and less-toxic alternative fuel that can be readily produced from a variety of vegetable plants in the US. The growth and harvest of these crops can help stimulate farm communities and also provide a protective measure from housing development pressures. In fact, a USDA economic study forecasts that if we use a B1 blend just for lubricity purposes this would generate more than $900 million to gross farm income while decreasing federal outlays.

Biodiesel is a sustainable energy source that can be used in any diesel engine with little to no engine modification that can help reduce our dependence on foreign oil. Testing has shown that there are significant emission benefits from using biodiesel with the exception of NOx. Until further emission testing is conducted with in-use engines, there is clearly not enough data for the experts to determine if NOx emissions will increase or decrease. Additionally, biodiesel can

reduce greenhouse gases with reduction in PM and CO_2. [42] Biodiesel is currently being used in over 400 truck fleets in the US and the distribution is also starting to be sold by the corner gas stations.

Section 757 of the 2005 Energy Act requires comprehensive research on biodiesel impacts on diesel engine currently in use and any foreseeable future designs. Congress has allocated $5 million per year for 2006 through 2010 to conduct and report on this testing.[43]

Biodiesel usage in home and industrial boilers is relatively a new market that started to evolve in 2001. Based on data collected from the Energy Information Agency, 5.5 billion gallons of home heating oil was consumed by the eleven Mid-Atlantic and Northeast states. This makes for a desirable blend market for biodiesel and one that should be taken seriously by biodiesel. Another driving force for the oil heat market to promote biodiesel is to regain market share it has lost over the last 20 years to natural gas. It is no secret that the heating oil industry has been loosing market share since the 1970's when 20% of the American households heated their home with oil. Today, the home heating oil market share is around 10%. Additionally, less than 4% of new homes that are built use heating oil as their primary heat source.

Biodiesel has not yet become a "household" name, nor is it the panacea to replace fossil fuels. However, biodiesel can help displace a large portion of our imported oil and clean up our air emissions. America needs to become more self-dependent for its fuel needs and begin to break its dependency on potentially unstable oil producing countries. As our economy and country continues to grow, there is great potential for biodiesel production and uses in the not only in the Commonwealth, but the US. Therefore educating, promoting and using biodiesel is a step in the right direction to break our addiction.

State Air Pollution Control Board's Authority

The subcommittee has considered what the State Air Pollution Board might do, if it wished, to promote the use of biodiesel fuel in the Commonwealth. There are several reasons why government might wish to encourage biodiesel fuel -- to provide an additional market for agricultural products and to reduce dependence on foreign fuels in the interest of national security, for example. We judge that only the goal of reducing air pollution would be within the Board's purview.

By statute the Board has the following powers to help promote the use of biodiesel to improve air quality:

- The power to make, or cause to be made, such investigations and inspections and do such other things as are reasonably necessary to carry out the provisions of this chapter, within the limits of the appropriations, study grants, funds, or personnel which are available for the purposes of this chapter, including the achievement and maintenance of such levels of air quality as will protect human health, welfare and safety (Va. Code Ann. 10.1-1306).

- Initiate and supervise research programs to determine the causes, effects, and hazards of air pollution (1307(A)).

- Develop a comprehensive program for the study, abatement, and control of all sources of air pollution in the Commonwealth; and advise, consult, and cooperate with agencies of the United States and all agencies of the Commonwealth, political subdivisions, private industries, and any other affected groups in furtherance of the purposes of this chapter (1307(A)).

- Submit an annual report to the Governor and General Assembly on or before October 1 of each year on matters relating to the Commonwealth's air pollution control policies and on the status of the Commonwealth's air quality (1307(G)).

- The Board may adopt by regulation emissions standards controlling the release into the atmosphere of air pollutants from motor vehicles, only as provided in Article 22 (Va. Code Ann. §46.2-1176 et seq.; 10.1-1307(B)).

- After any regulation has been adopted by the Board pursuant to §10.1-1308, it may in its discretion grant local variances there from, if it finds after an investigation and hearing that local conditions warrant (1307(C)) In addition, under 1308(A) the Board has the power, after having studied air pollution in the various areas of the Commonwealth, its causes, prevention, control and abatement, to promulgate regulations, including emergency regulations, abating, controlling and prohibiting air pollution throughout or in any part of the Commonwealth in accordance with the provisions of the Administrative Process Act (§2.2-4000 et seq.).

Recommendations

The SAB has consulted DEQ as to what specific actions within the Board's power might help promote the use of biodiesel fuel. The Board may wish to consider the following suggestions:

1. Encourage the DEQ regions to keep biodiesel in mind when creating and negotiating SEPS (Supplemental Environmental Programs) from enforcement actions. Possible projects could include:

- Use SEP money for grants to state universities to research the total economic, feasibility and emission impact that biodiesel could have on the Commonwealth. This would complete one of the action items from the Secretary of Agriculture and Forestry study. Additionally, SEP money could be use to study emission on fleets that are currently using biodiesel, but do not have the financial resources to conduct such as study. Emission studies could also be conducted on home and industrial furnaces that have or will switch to biodiesel blends.

2. Investigate the use of biodiesel as BACT (Best Available Clean Technologies) for new facilities, since it emits less SO2; if biodiesel seems viable as BACT, include it as an option in standard permit language.

3. Encourage the use of biodiesel at facilities with significant amounts of off-road engines onsite, such as ports, military bases, and large trucking hubs.

4. Ask the Director of DEQ's Division of Environmental Enhancement to incorporate the use of biodiesel as part of E4 plans for various facilities achieving E4 status (Extraordinary Environmental Excellence) under Virginia's Environmental Excellence Program.

5. Encourage the distribution and logistics to get market biodiesel at truck stops and regular service stations.

6. Promote the use biodiesel as a cleaner alternative to other liquid fuels in boilers for both home and industrial heating.

7. Investigate whether producing biodiesel from yellow grease would qualify tax credit for business under Virginia Recycling Act.

Appendix A

Listed below is a summary of specific advantages listed within the National Biodiesel Board website www.biodiesel.org/resources/fuelfactsheets.

Other Advantages with using Biodiesel

1. Non-Toxic

One hundred percent biodiesel is rapidly biodegradable and completely non-toxic, meaning spillages represent far less of a risk than fossil diesel spillages. Biodiesel has a higher flash point than fossil diesel and so is safer in the event of a crash. Within 28 days, B100 will degrade in water by 85 to 88 percent. A blend of B20 degrades twice as fast as No. 2 diesel fuel alone. Ordinary table salt is nearly 10 times more toxic than biodiesel.

Additional Environmental Impacts:

Using a blend of B2 in on-road engines will:

- *Reduce poisonous carbon monoxide emissions by more than 35 million pounds annually*.
- *Reduce ozone forming hydrocarbon emissions by almost 4 million pounds annually.*
- *Reduce hazardous diesel particulate matter by almost 3 million pounds annually.*
- *Reduce acid rain-causing sulfur dioxide emissions by more than 3 million pounds annually*.
- *According to the EPA, diesel exhaust contains harmful polycyclic organic matter (POM) that can affect the reproductive, developmental, immunological and endocrine (hormone) systems in humans and wildlife. Compared to the 700 million gallons of diesel fuel that would be used, the 2 percent biodiesel would reduce POM impacts by more than 80 percent*.

Since biodiesel is produced from vegetable crops that are grown and harvested each year, some experts call it a closed carbon loop system or liquid solar power. The use of 2 percent biodiesel each year in the U.S. would:

- *Reduce the life cycle carbon dioxide emissions more than 11 billion pounds annually*
- *Extend the fossil fuel diesel supply almost four-fold for every gallon of diesel replaced by biodiesel*.

Economic Benefits:

The NBB estimates that if a blend of biodiesel at 1 percent is used for lubricity purposes the following economic benefits would occur:

- *An annual demand of 350 million gallons of biodiesel*
- *Utilization of over 250 million bushels of soybeans*
- *Add a minimum of $0.35 to the value of a bushel of soybeans, based on an economic analyses conducted by the USDA*
- *Add more than $900 million to gross farm income while decreasing the federal outlays under the soybean marketing loan program in similar amounts*
- *Potentially reduce fleet operating costs through increased equipment life*

Other economic impacts would likely follow such as increased farm employment as well as additional federal and state tax revenues.

Appendix B

In the following pages are two products that are solicited as an alternative fuel. This is information is provided as an example of additives and is not be construed as an endorsement of either product. Further information can be found at: www.lubrizol.com/PuriNOx/fueltechnology.asp.

PuriNOx™ Technology

Low-Emission Diesel Fuel System

An instant, economical solution that reduces pollution emitted from diesel-powered engines

The Lubrizol Corporation's PuriNOx™ Technology is a new "fill-and-go" approach to helping owners and operators of diesel-powered vehicles and equipment clean up the air. Combining diesel fuel, purified water and the patented PuriNOx additive package, this low-emission diesel fuel system produces a water-in-diesel fuel emulsion that instantly and significantly reduces emissions from existing diesel engines, new and old, without expensive engine modifications, replacements or complicated hardware add-ons.

PuriNOx produces an emulsion that typically slashes smog-forming nitrogen oxide (NOx) emissions by 30 percent and particulate matter (PM), or soot, by 50 percent.

PuriNOx reaches vehicle and equipment fleet operators via fuel marketers and distributors that mix the fuel's components in an electronically-controlled and automated proprietary blending unit to produce the finished product for end users, who can experience the immediate features and benefits of the technology straight from the pump.

The Lubrizol Corporation developed the PuriNOx Technology with the assistance of testing from Caterpillar Inc. (CAT) in response to the industry's growing demand for innovative emissions control solutions. CAT continues to support field evaluations of PuriNOx-powered fuel in its engines to validate performance in both on- and off-road applications.

The Lubrizol Corporation has several blending partners in North America and Europe: Ramos Oil, West Sacramento, CA; ChevronTexaco, Montebello, CA; RV Jensen, Fresno, CA; J.A.M. Distributing, Houston, TX; BP, London, England; Green Oils, Genoa, Italy; Kuwait Petroleum Italia (KPIT), Naples and Milan, Italy; and Blanco Petroli, Sicily.

Further information can be found at: www.o2diesel.net/products.php

THE BENEFITS OF OXYGENATING DIESEL

The benefits of adding oxygenates to motor fuels are well documented, but it is only recently that new technology has made oxygenated diesel fuel economically and technically viable. Supported by its ethanol-blended diesel fuel, O2Diesel, Corp. is a leader in delivering cleaner-burning diesel fuels to global markets.

- O2Diesel™ is a "fill and go" clean diesel technology available for centrally-fueled fleets in large urban areas plagued with air quality problems.
- O2Diesel™ reduces diesel equipment regulated and unregulated exhaust emissions, including greenhouse gases.
- O2Diesel™ reduces harmful emissions from diesel engine exhaust including particulate matter, oxides of nitrogen, carbon monoxide, and carbon dioxide.
- O2Diesel™ provides cleaner combustion with decreased engine corrosion, reduced cylinder wear and extended lubricant life.
- O2Diesel™ can be used engines designed for conventional diesel fuel without special modifications or changes.

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